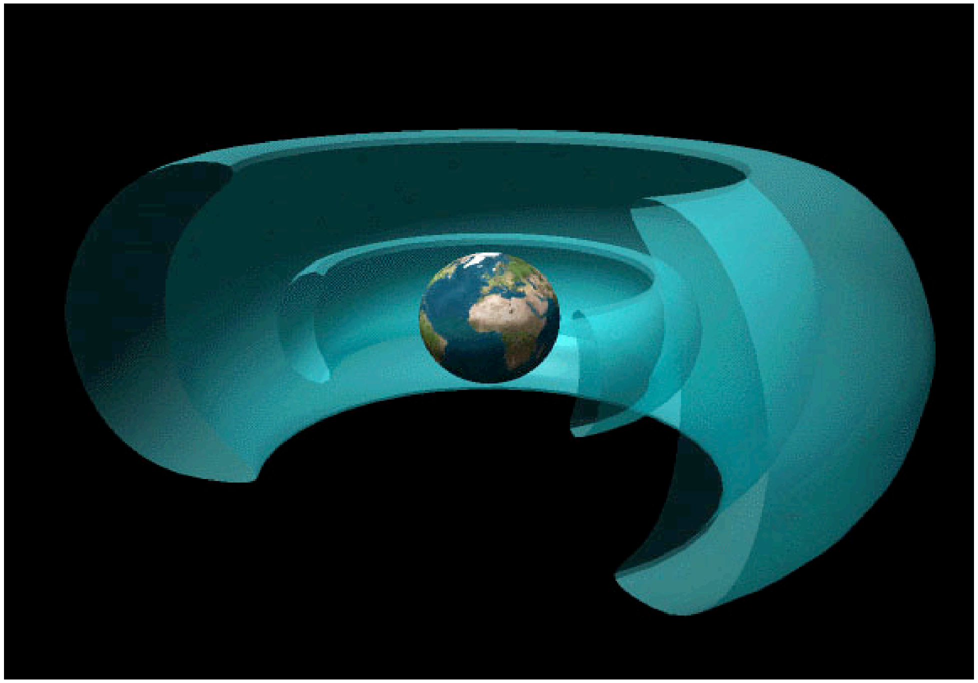
Radiation Belt Mappers



Presentation at Living With a Star Workshop

R. A. Hoffman

B. L. Giles

Radiation Belt Mappers

Mission Objectives

- Obtain scientific understanding of the sources, transport and losses of radiation belt particles
  - with special emphasis on penetrating radiation during geomagnetic storms
- Acquire the data required for the development of empirical and science-driven radiation belt models
- Acquire the data for real time telemetry needed by the operations community

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Measurement Goals

Science Community

- Coverage of full phase space distributions over local time and altitude
- Electric and magnetic fields characterizations over frequency domain of interest to the radiation belts

User Community

- Data products for specification and predictive models
- Data products for real-time telemetry for the operations community

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Phases of the Program

First phase: utilization of current and near future missions

- Targeted data analysis activities
- Development of modeling techniques and procedures
- Instrument development activities

Second phase: primary flight phase

- Launch about 2008
- Two year lifetime, five year goal
- Data analysis

Third phase: targeted flights to characterize radiation belts

- TBD missions
- TBD instrumentation

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Disclaimer

- The Radiation Belt Mapper mission scenario to be presented represents one possible approach.
- Other approaches are possible and should be studied during the formal definition phase.

Therefore nothing to be presented should be considered definitive.

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Bounds of Responsibility

- Region of interest extends to geosynchronous altitude
- Substorm effects included only as input to radiation belts
- Input to radiation belts from beyond geosynchronous orbit provided by non-LWS programs
- Polar cap precipitation measurements:
  Galactic cosmic ray intensities are domain of Sentinels
  Solar cosmic ray characteristics are domain of Sentinels
- Auroral precipitation is domain of Ionospheric Mappers
- Geomagnetic cutoff latitudes for galactic and solar cosmic rays is task of Sentinels and modeling
- South Atlantic anomaly is domain of RBM with instrumentation possibly carried by Ionospheric Mapper spacecraft
- Radiation belt precipitation is domain of RBM with instrumentation possibly carried by Ionospheric Mapper spacecraft

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RBM Pre-Formulation Activity Timeline

February 15	Started with a clean slate
March 9	Pre-Formulation Definition Team Meeting
March 13-15	Integrated Mission Design Center (IMDC)
March 20-23	Space Weather Conference in Florida
April 20	Resources Analysis Office results
May 2	Space Weather Week in Boulder
May 8 & 9	Return to IMDC
May 10 - 12	LWS Workshop

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Pre-Formulation Definition Team

Dan Baker	U. Colorado
Janet Barth	NASA/GSFC
Col. Mike Bonadonna	HQ USAF/XOW
Don Brautigam	AFRL
Clive Dyer	DERA
Joe Fennell	Aerospace Corp.
Shing Fung	NASA/GSFC
Dale Ferguson	NASA/Glenn
Barbara Giles	NASA/GSFC
Michael Golightly	NASA/JSFC
Bob Hoffman	NASA/GSFC
Mary Hudson	Dartmouth College
Billy Kauffman	NASA/MSFC
Barry Mauk	JHU/APL
Don Mitchell	JHU/APL
Pat O'Neill	NASA/JSFC
Geoff Reeves	LANL
Howard Singer	NOAA/SEL
Richard Thorne	UCLA
Dick Wolf	Rice University
John Wygant	U. Minnesota

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Products of Definition Team

- Requirements definition
- Requirements evaluation
- Candidate orbit scenarios
- Instrumentation parameter tables
- Orbit evaluation approach

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Requirements Evaluation - part 1

- Regions:
  Inner belt
  Slot belt
  Plasmasphere
  Outer belt, inc. ring current
- Parameter (e.g.):
  Proton fluxes
  Electron fluxes
  Heavy ions
  Waves
  E fields
- Purpose
- Priority:
  Users
  Science

REGION	PARAMETER	PURPOSE	PRIORITY USERS	PRIORITY SCIENCE	PARAMETER RANGE	PARAMETER RESOLUTION	LOCATION	ANGULAR RANGE	ANGULAR RESOLUTION	TEMPORAL RESOLUTION	LT RESOLUTION	OTHER
Inner belt	Proton fluxes	Solar cell damage	1	3	<50 MeV	100 percent	L = 1.1 - 2.5	Omni or crude distributions	30 deg.	Days	Statistical	
		Dose, bkgnd	1	3	5 - 500 MeV		L = 1.1 - 2.5				1 position	
		SEEs & biological	1	3	>50 MeV		L = 1.1 - 2.5					
		CCDs (e.g., Chandra)	1	3	0.01 - 1 MeV	50 - 100%	L = 1.1 - 7			Day or less		
		Model improvement	1	N								
	Heavy ions						L = 1.1 - 2.5					
	Electron fluxes	Background & deep dielectric charging	2	3	0.05 - 10 MeV	100 percent	L = 1.1 - 2.5	Crude distributions	30 deg.	Day	Statistical	Difficult to measure
	Protons in South Atlantic anomaly	S/C anomalies and interference	2	3	10 - -450 MeV	100%	L = 1.1 - 2.5	Distribution in loss cone	5 deg.	Days	Statistical	
		EVA timing	1	N	10 - -450 MeV	100%	L = 1.1 - 2.5					
		STS/ISS crew exposure	1	N	10 - -450 MeV	100%	L = 1.1 - 2.5					
		ISS shielding design	1	N	10 - -450 MeV	100%	L = 1.1 - 2.5					
	Atmos. Density	Proton lifetimes	1	3	Total density	N/A	L = 1.1 - 2.5	N/A	N/A	Days	Statistical	
	Waves	Accel./transport/loss	N	3			L = 1.1 - 2.5	Lat. distrib.	10 - 20 deg	Hours	Statistical	Amplitudes and polarizations
	Magnetic field	PA distribution	N	N	N/A	N/A	L = 1.1 - 2.5	N/A	N/A	N/A	N/A	
Slot belt	Proton fluxes	EVA crew exposure	2	1	0.01- 50 Mev	50%	L = 1.75 - 2.75	Near equator distributions	15 - 20 deg	< 1 day	None	Predict existence and lifetime
	Electron fluxes		2	1	to 20 MeV							
	Heavy ions to O		N	3	10-40 MeV/nu							
	Waves	Scattering in slot	N	1	ULF - VLF or higher VLF transmitters 10 -25 kHz		L = 1.5 - 2.5					

Actual chart is available as separate file: RBM_requirements.pdf

Radiation Belt Mappers

Requirements Evaluation - part 2

- Parameter: range (e.g., energy), resolution
- L value range
- Type of distribution
- Temporal resolution
- Local time resolution

REGION	PARAMETER	PURPOSE	PRIORITY		PARAMETER		LOCATION	ANGULAR		TEMPORAL	LT	OTHER
			USERS	SCIENCE	RANGE	RESOLUTION		RANGE	RESOLUTION	RESOLUTION	RESOLUTION	
Inner belt	Proton fluxes	Solar cell damage	1	3	<50 MeV	100 percent	L = 1.1 - 2.5	Omni or crude distributions	30 deg.	Days	Statistical 1 position	
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	Electron fluxes		2	1	to 20 MeV	50%	L = 2 - 3.5	Distributions	15 deg.	< 1 day	None	
	Heavy ions to O		N	3	10-40 MeV/nuc							
	Waves	Scattering in slot	N	1	ULF - VLF or higher VLF transmitters 10 -25 kHz		L = 1.5 - 2.5					

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Requirements Evaluation

- Regions:
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- Parameter (e.g.):
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  - Electron fluxes
  - Heavy ions
  - Waves
  - E fields

- Purpose

- Priority:
  - Users
  - Science

- Parameter: range (e.g., energy), resolution
- L value range
- Type of distribution
- Temporal resolution
- Local time resolution

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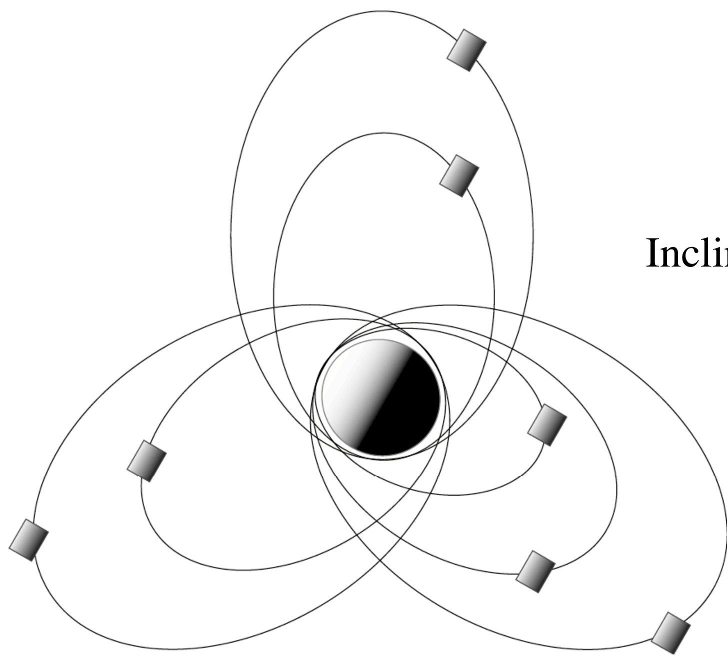
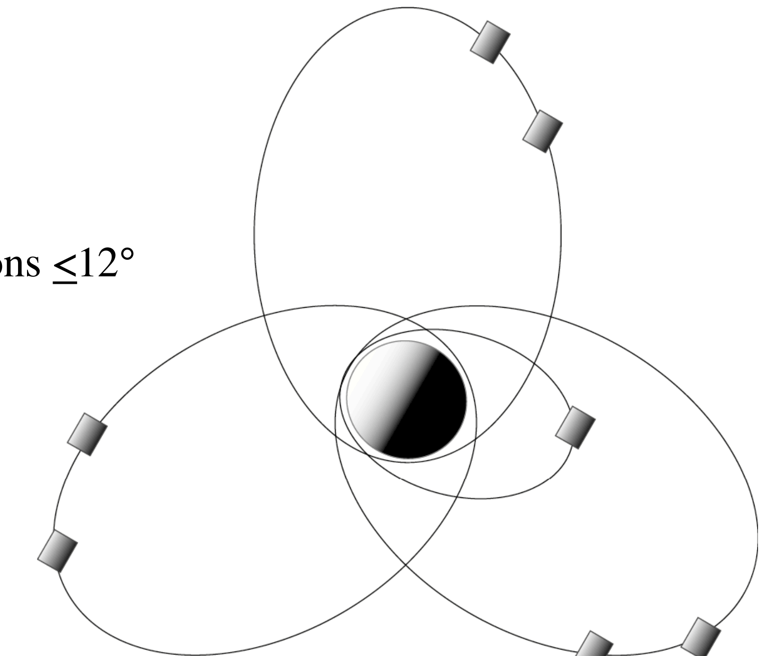
Candidate Orbits - part 1

All candidate orbits have an additional spacecraft with 2.8 Re apogee for inner belt and slot observations



Inclinations $\leq 12°$



6 S/C on 3 Nested Petals

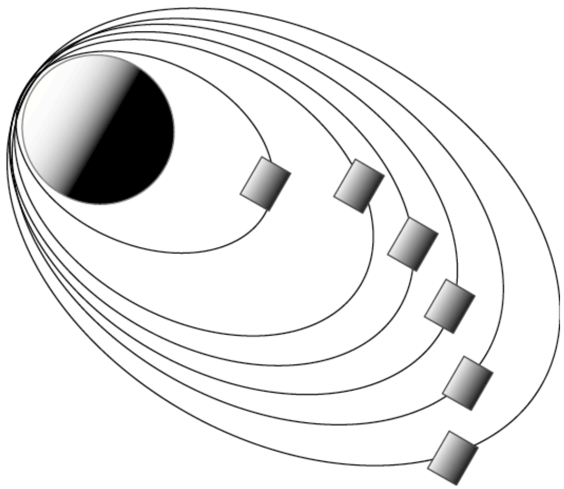
- Inner and outer sets of petals precess differentially with LT
- Greater distribution in radial distance and local time

6 S/C on 3 Petals

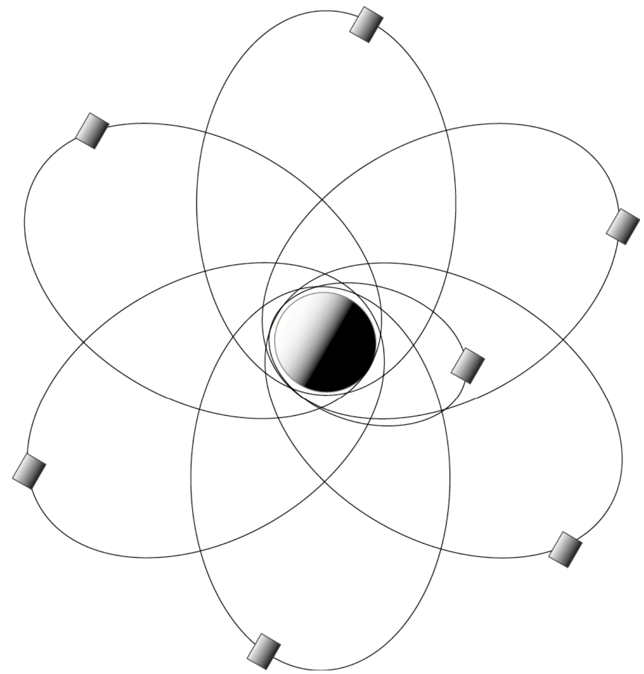
- 4 semi-radial cuts per period
- Higher time resolution for L distribution

Radiation Belt Mappers

Candidate Orbits - part 2



Inclinations $\leq 12°$



5 S/C on 5 Nested Orbits

- All precess differentially with local time
- Simple orbit insertion

6 S/C on 6 Even Petals

- With minimal station keeping, petals remain evenly spaced in local time
- Affords better local time distribution
- Radial cuts in same direction simultaneously, with station keeping

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Evaluation of Candidate Orbits

- Work in progress
- Need for one or more of the spacecraft to be at intermediate inclination remains an open issue
- Nested option eliminated upon initial evaluation
- Initial IMDC and RAO results discouraged further evaluations
- Current launch approach does not eliminate remaining candidates

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Spacecraft Requirements

- Spin stabilized, 6 - 10 RPM
- Sun pointing within ~15°
- Identical spacecraft
- Standard aerospace manufacturing/fabrication practices (ideal for industry participation)
- Two-year lifetime, five year goal
- High radiation environment
- Continuous downlink for real-time telemetry
- Full instrument complement on each spacecraft

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Candidate Instruments in Priority Order

- High-energy particles (1-20 MeV protons; 1-10 MeV electrons)
  Mid-energy particles (30 keV to 1 MeV)
  Very high energy protons (20-500 MeV) on low apogee spacecraft
- Flux gate magnetometer
- Electric field probes (2 orthogonal axes in spin plane)
- Low energy ions and electrons (30 eV - 30 keV)
  Option: include mass analysis
- Search coil magnetometer
- Thermal plasmas density and temperature (< 100 eV)
  Option: include energy and mass analysis

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Constraints Imposed on Feasibility Study

- NASA approved launch vehicle
- Launch from U.S. launch site
- Use of single Delta II or equivalent in cost
- Spacecraft components currently available or available near term
- Instruments available today
- Full environmental testing on all copies
- Cost analysis based on past history
- Cost analysis based on no commonality with other LWS missions

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Mass to Orbit via Single Vehicle

- Launch vehicle puts all spacecraft in 500 km x 8400 km, 28° inclination orbit
- Low-apogee and first high-apogee spacecraft are boosted to correct apogees and 12° inclination
- Orbital precession moves the local time of apogee for the remaining satellites with respect to the first satellites
- As each remaining spacecraft moves to the correct local time, it is boosted to the final apogee and its inclination is changed to 12°
- Insertion technique applicable to all candidate orbit configurations

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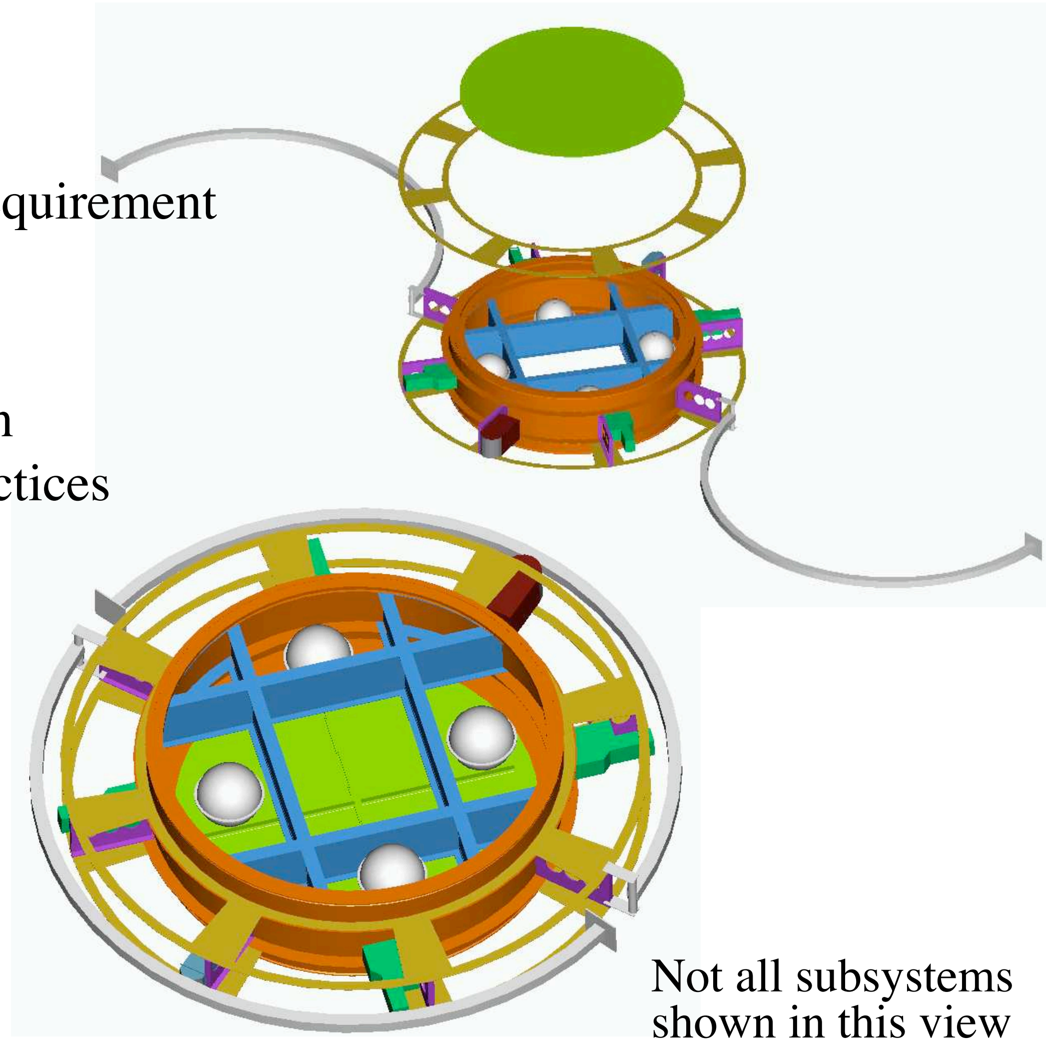
Possible Spacecraft Design

- Mission unique spacecraft design
- Radiation shielding and stacking requirement precludes use of RSDO
- Baseline materials to be composite
- Few new manufacturing/fabrication techniques, standard aerospace practices (ideal for industry participation)
- Hinged magnetic field booms
- Deployable electric field antennas
- No unusual integration difficulties



Not all subsystems shown in this view

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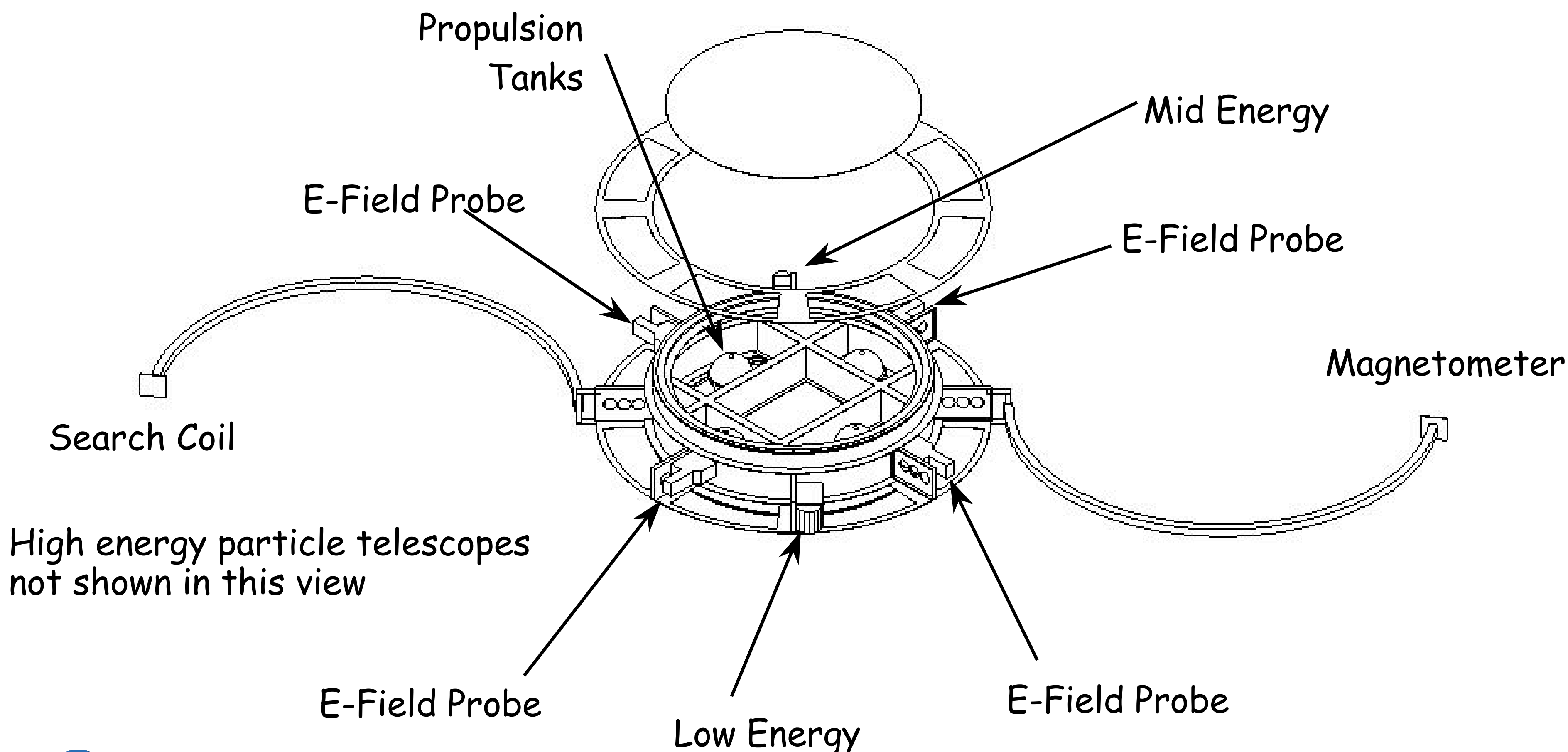
Possible Experiment Layout

Not all subsystems shown in this view



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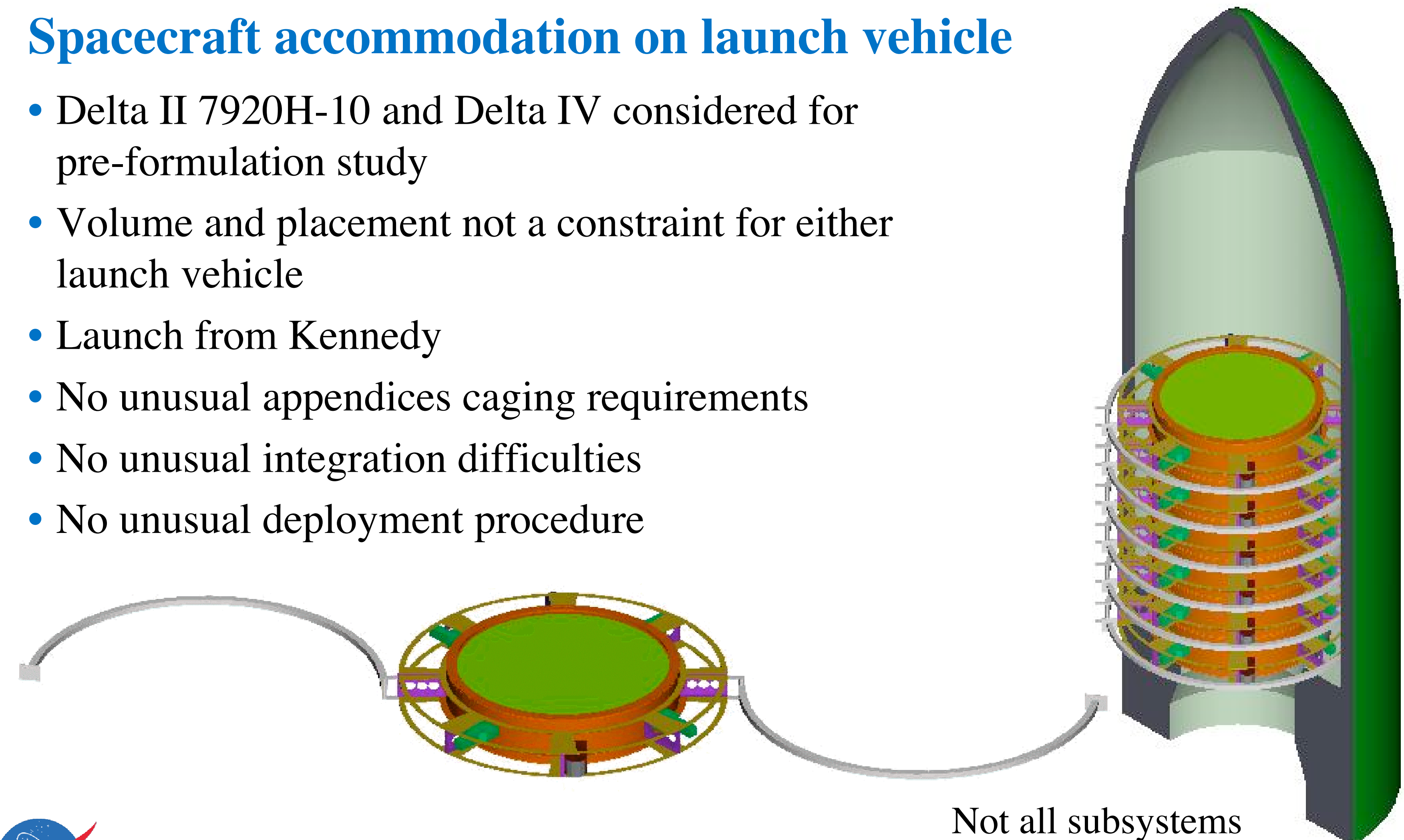
Spacecraft accommodation on launch vehicle

- Delta II 7920H-10 and Delta IV considered for pre-formulation study
- Volume and placement not a constraint for either launch vehicle
- Launch from Kennedy
- No unusual appendices caging requirements
- No unusual integration difficulties
- No unusual deployment procedure



Not all subsystems shown in this view

Comparison Between
Definition Team Program and Definition Study

PARAMETER	DEFINITION TEAM PROGRAM	IMDC TECHNICAL DEFINITION	RAO EVALUATION
Number of spacecraft	7	5-6 (assumes 1 launch vehicle)	3 (assumes 1 launch vehicle)
Maximum apogee, Re	6.5	6.5	6.5
Inclination capability	< 18°	12°	< 18°
Instrument complement	8	7	8
Real-time data Science data	100 bps 67 kbps	100 bps 67 kbps	500 bps 67 kbps
Attitude determination	0.3°	0.3°	0.3°
Imager spacecraft w/ IM	1	0	0

RBM Challenges - Part 1

- Develop core mission scenario based on realistic assessment of technological advances in the next few years, that
  a) avoids current single source suppliers
  b) allows concrete basis for cost estimates.
- Find affordable launch scenario that maximizes number of spacecraft on single launch vehicle and achieves minimum inclination (at least for some spacecraft).
- Develop concepts for acquisition of instruments, with calibrations, testing, software development for operations and data processing, post-launch instrument validation, operations and data processing while minimizing staffing.
- Develop concepts for fabrication and calibration of multiple copies of instruments while minimizing costs.

RBM Challenges - Part 2

- Develop concepts for fabrication and testing of multiple copies and integration of spacecraft while minimizing costs.
- Develop environmental testing approach for multiple, identical spacecraft that would assure reliable spacecraft and instruments while minimizing testing costs.
- Evaluate, especially with Ionosphere Mappers mission, spacecraft systems commonalities
- Seek partnering to acquire:
  a) additional launch opportunities for spacecraft
  b) flights of opportunity for instruments
  c) complementary spacecraft missions